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TECHNICAL NOTE NO. 1428
OCTOBER 1961

AN INTERIM REPORT ON THE STUDY OF PARAMETERS THAT AFFECT THE ACCURACY OF AUTOMATIC RIFLES (U)

H. P. Gay
S. S. Lentz
W. M. Werner

Ordnance Management Structure Code No. 5520.17.433C0.03

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HPGay/SSLentz/WMWerner/rc
Aberdeen Proving Ground, Md.
October 1961

AN INTERIM REPORT ON THE STUDY OF PARAMETERS THAT AFFECT THE ACCURACY OF AUTOMATIC RIFLES (U)

(UNCLASSIFIED) ABSTRACT

This ~~interim~~ report is a brief summary of the work being done by the Applied Mechanics Branch, IBL, for the All-Purpose Hand-Held Weapon (APHHW). It gives some ideas of the present trends of thought and some indications of ways to improve the accuracy of automatic fire. Details of the studies and the final conclusions which might be reached will be given in subsequent reports.

[redacted]

(UNCLASSIFIED) INTRODUCTION

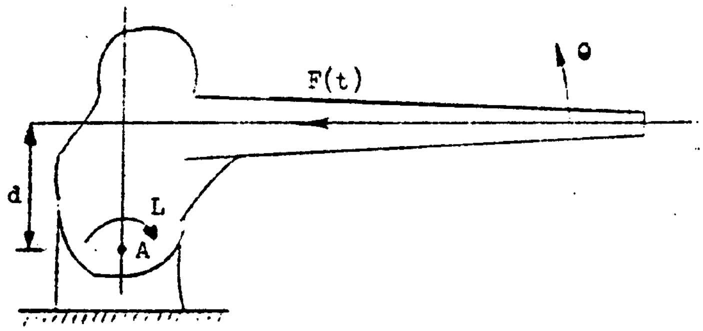
To increase the effectiveness of the APHHW, it has been proposed to fire a group of three rounds having a standard deviation of dispersion of two or three mils.[(1)*] Experience has shown that automatic rifles have larger dispersion, so the Ordnance Weapons Command requested BRL to study the various factors that influence the accuracy of the man-rifle system. It is hoped that the results of this study will provide a guide, and possibly some basic data, for designing the APHHW.

*Superscripts in parenthesis indicate references.

(UNCLASSIFIED) A MODEL OF THE MAN-WEAPON SYSTEM

To determine the importance of the physical parameters that affect accuracy, it was decided to represent a man-weapon system by a physical model. Since the man and the weapon form a complex physical system an empirical approach was used and the system was described by one combined single model. An inertial model without constraints was considered first. It was found that this model could not be used because the actual displacement of the third shot on the target was less than that predicted by the model. A restraining torque was then added to provide a better model.

The present model is described below:



I = the moment of inertia about A of the man-weapon system.

Θ = the angular displacement.

F(t) = the force produced by firing.

d = the distance from the axis of the bore to the fixed pivot A.

L = a constant restraining torque.

The model consists of some unknown portion of the man which is rigidly connected to the rifle and rotates about some fixed point A. The moment of inertia about A of the combined mass is I. The upward angular motion Θ of the system is produced by the torque F(t)d, which is opposed by a restraining torque L. This restraining torque may be produced by the weight of the system and/or some unbalanced elastic forces between the man and the rifle, and/or some resistance produced by the pivot. (For the present time, the details of these forces, etc., are ignored.)

The equation of motion of this system is obtained from the sum of the torques about the fixed pivot A. Thus, with the dot notation indicating differentiation with respect to time:

$$\sum \text{torque} = 0 = F(t)d - L - I\ddot{\theta}\,, \quad \text{or}$$

$$I\ddot{\theta} = F(t)d - L\,. \tag{1}$$

The force $F(t)$ is produced by the powder pressure acting through the gun mechanism. Since this force lasts approximately one millisecond, Δt, and the time T between shots is much greater (30 ms at 2000 spm), we will assume that the initial motion is impulsive.(2) Then from the conservation of momentum:

$$\int_{\Delta t} F(t)dt = \mathcal{J} = \left(W_p + \frac{W_c}{2}\right)\frac{V_p}{g} + \frac{K}{g} = 0.78 \text{ lb sec}^* \tag{2}$$

where

$$W_p = 2.31 \times 10^{-3} \text{ lbs}$$

$$W_c = 2.21 \times 10^{-3} \text{ lbs}$$

$$V_p = 4600 \text{ ft/sec}$$

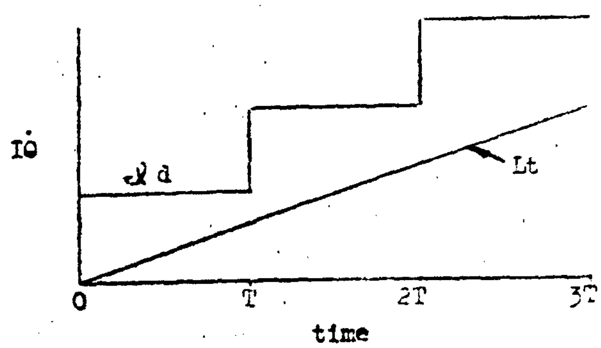
$$\frac{K}{g} = 0.295 \text{ lb-sec}\,.$$

The integration of Equation (1) then yields:

$$\begin{aligned} I\dot{\theta} &= \mathcal{J}d - Lt, \quad 0 \leq t \leq T \\ &= 2\mathcal{J}d - Lt, \quad T \leq t \leq 2T \\ &= 3\mathcal{J}d - Lt, \quad 2T \leq t \leq 3T\,. \end{aligned} \tag{2}$$

*See Appendix I of Reference 3.

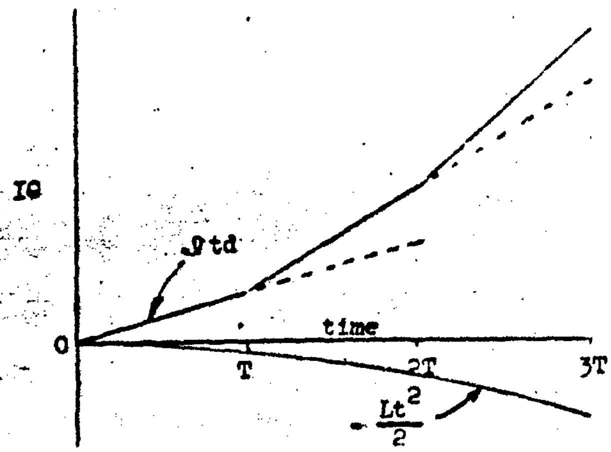
The right side of this equation is shown below:



Integration of Equations (2) yields

$$I\Theta = \mathcal{J}td - \frac{Lt^2}{2}, \quad 0 \leq t \leq T$$
$$I\Theta = \mathcal{J}Td - \frac{Lt^2}{2} + 2(\mathcal{J}d)(t - T), \quad T \leq t \leq 2T \tag{3}$$

This equation is shown below:



For the later investigation, we will be interested in the motion immediately after each shot is fired. The values of $I\dot{\theta}$ and $I\theta$ are shown in the following table:

	time	$I\dot{\theta}$	$I\theta$
first shot	$0 + \Delta t$	ωd	0
second shot	$T + \Delta t$	$2\omega d - LT$	$\omega Td - \frac{LT^2}{2}$
third shot	$2T + \Delta t$	$3\omega d - 2LT$	$3\omega Td - 2LT^2$

To establish the physical constants of the model, we will assume that the angular deflection θ can be obtained with sufficient accuracy from the target pattern of a three-round burst. Thus the deflection α at the target is:

$$\alpha_1 = \theta(0 + \Delta t) = 0 \qquad (3)$$

$$\alpha_2 = \left(\omega Td - \frac{LT^2}{2}\right)\frac{1}{I} \qquad (4)$$

$$\alpha_3 = \left(3\omega Td - 2LT^2\right)\frac{1}{I} . \qquad (5)$$

Solving Equations (4) and (5) simultaneously:

$$\frac{L}{I} = \frac{2(3\alpha_2 - \alpha_3)}{T^2}$$

$$\frac{d}{I} = \frac{(4\alpha_2 - \alpha_3)}{\omega T} .$$

The two numbers, L/I and d/I, thus provide a model which is in accord with the observed target pattern. The model can then be used to estimate the effects of changes of ω and T on accuracy.

It is emphasized here that the two numbers, L/I and d/I, do not necessarily have an important physical significance. They are empirical and may be different for different man-weapon systems.

It should be noted that the angular velocity $\dot{\Theta}$ adds a vertical component u_v to the velocity of the projectile given by:*

$$u_v = \ell\dot{\Theta}, \quad \text{where } \ell = \text{horizontal displacement from A to muzzle.}$$

The corresponding deflection on the target is:

$$\frac{\ell\dot{\Theta}}{V_p} .$$

In most cases this effect is small. It can be calculated from the data.

*See p. 21-22 of Reference 3.

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(CONFIDENTIAL) RESULTS OF TARGET FIRINGS

Previous firings of service weapons provided a good basis for establishing the model. However, it was felt that it was not feasible to evaluate the physical parameters from those firings and then to extrapolate the results to provide data for the APHHW. In those firings the dispersion, impulse, and weapon weight were considerably greater and the rate of fire considerably smaller than that anticipated for the APHHW. It was therefore decided to fire a series of tests with the Aircraft Armaments' weapon which is closer to the expected APHHW than the service weapons. The Weapon Systems Laboratory coordinated the tests, HEL provided the riflemen and recorded the data, D&PS provided the facilities, and Aircraft Armaments furnished the weapon.

To obtain representative data for a single condition, nine riflemen fired bursts of three rounds each. The target pattern for each three-round burst thus provide two vertical deflections* (from the first shot) which were used to evaluate the two parameters of the model. The results are shown in Table I. The standard deviations of d/I indicate that there is little significant difference from rifleman to rifleman. Thus, it is reasonable to use the mean value of d/I to characterize the group. This mean value is not very precise, as indicated by its standard deviation. The same general remarks apply to the parameter L/I. It appears that there is no correlation between these results from automatic fire and the rifleman's rating with the M1 Rifle which is based on his ability to fire single shots accurately.**

One way to improve the accuracy is to fire at a very high cyclic rate so that the weapon has little time to move between shots. To provide an estimate of the rate necessary to accomplish this, a curve of Θ_3 versus rate

*The horizontal deflections generally were small and relatively inconsistent so that they are not of primary interest at this time.

**Aiming error has been "stripped out" of the automatic fire data by using the target impact of the first round as the origin of the coordinate system.

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TABLE I

CALCULATED VALUES FOR L/I and d/I BASED ON THE VERTICAL DISPERSION ON THE TARGET

Rating of Rifleman on M1 Rifle	Rifleman	Height	Weight	No. of Bursts	$\frac{L}{I}$	$\frac{\sigma_L}{I}$	$\frac{d}{I}$	$\frac{\sigma_d}{I}$
			lbs		sec^{-2}	sec^{-2}	$lb^{-1}\ sec^{-2}$	$lb^{-1}\ sec^{-2}$
Expert	A	6'1"	180	10	14.8	8.2	0.574	0.202
	B	5'9"	160	10	27.8	13.1	0.933	0.276
	C	6'0"	210	5	19.1	11.0	0.674	0.251
	D	6'4"	215	5	3.5	23.2	0.312	0.597
Sharp-Shooter	E	5'9"	155	5	15.0	10.5	0.563	0.266
	F	5'11"	200	5	19.0	6.7	0.705	0.209
	G	5'10"	165	5	17.0	10.7	0.636	0.239
Marksman	H	6'0"	190	5	6.9	9.0	0.297	0.254
	I	5'8"	150	5	18.2	10.1	0.662	0.257
	Mean	5'11"	179		16.7	11.2	0.624	0.280
						7.3*		0.203*

*Calculated from previous column.

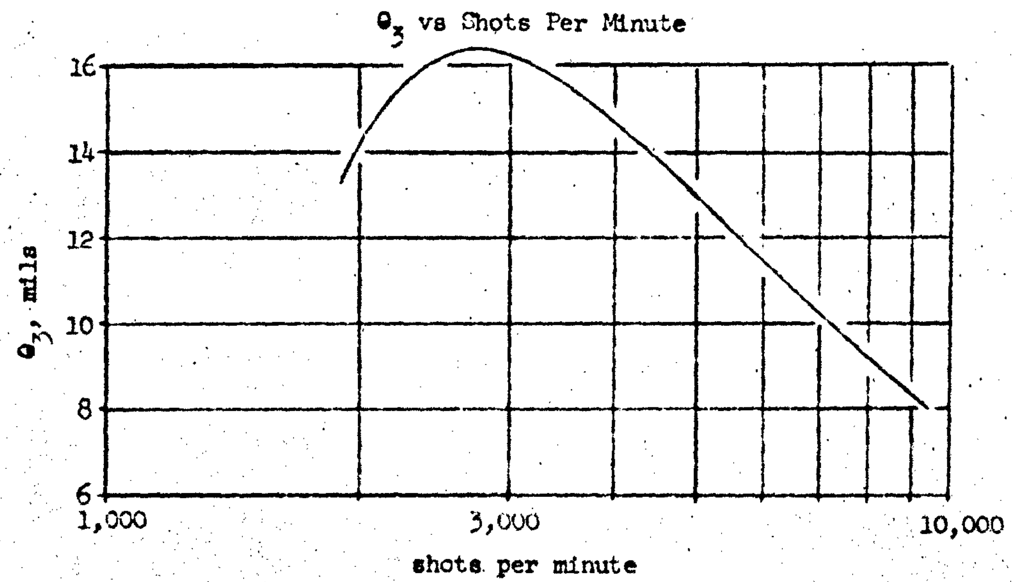
W_g = weight of weapon = 4.70 lbs.

I_{CG} = moment of inertia of weapon about the CG = 0.106 lb ft sec^2.

I = moment of inertia of weapon about the center of butt plate = 0.434 lb ft sec^2.

$\mathcal{J}$ = 0.78 lbs sec (see p. 7).

was calculated from Equation (5) using the mean values of d/I and L/I obtained from the firing data. The results are shown below.

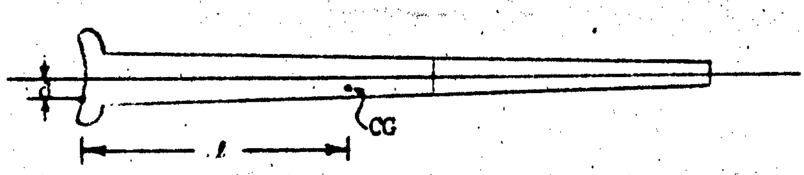


Note that if θ_3 must be equal to or less than eight mils, the cyclic rate should be about 10,000 shots per minute.

(CONFIDENTIAL) METHODS OF IMPROVING THE ACCURACY

Experience and previous investigations have shown that the drop of the stock plays an important part in the climb of the target pattern of a rifle. Since a straight stock reduces the climb, we will make a few rough calculations to indicate "how straight" a stock must be to meet the desired accuracy of the APHHW.

Assume, for simplicity, that the rifle is pinned at the man's shoulder which is rigid, as in Reference 3. A diagram of a probable weapon is shown below.



$$\ell = 1.56 \text{ ft}$$

$$W = 4.70 \text{ lbs}$$

$$I_{CG} = 0.106 \text{ lb ft sec}^2$$

$$I = I_{CG} + \frac{W\ell^2}{g} = 0.436 \text{ lb ft sec}^2$$

$$T = 0.030 \text{ sec (2000 spm)}$$

$$\mathcal{J} = 0.783 \text{ lb sec.}$$

For impulsive loading, Equation (5) applies so that:

$$\theta_3 = \frac{3\mathcal{J}\,Td}{I} - \frac{2LT^2}{I}\,.$$

To further simplify the problem, it will be assumed that the man exerts no restraining torque, (L = 0) during the burst. Then:

$$d = \frac{\theta_3 I}{3\mathcal{J}\,T}\,.$$

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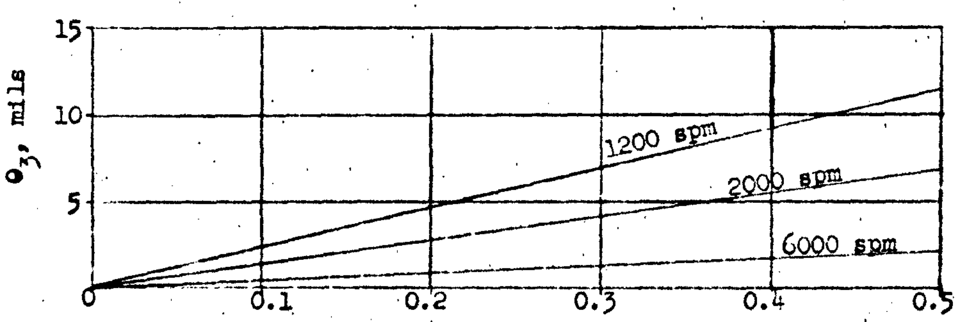
The graph below shows the calculated values of θ_3 vs d for various rates of fire.



If we say that θ_3 must be about four mils, then d should be about 0.28 inch for a weapon firing 2000 spm. It is important to remember that d must be small for the straight stock weapon because the cyclic rate of conventional gun mechanisms appears to be limited to about 3000 spm. The variation of d from man to man may be relatively large and thus be detrimental to the accuracy.

The "soft" recoil system* also has been proposed to improve the accuracy. By the methods used to derive Equation (5) and those of Reference 3, it can be shown that for a rifle with a perfect soft recoil system:

$$\theta_3 = \frac{1}{I}(Fd - L)\ 2T^2 , \qquad F = \text{average recoil force}$$

or

$$\theta_3 = 2T(\Omega \frac{d}{I} - \frac{L}{I} T) .$$

A comparison of the above equation with Equation (5) shows that d for a weapon with a soft recoil system is three halves of that for the ordinary weapon - a rather small difference.

*See Appendix III of Reference 3.

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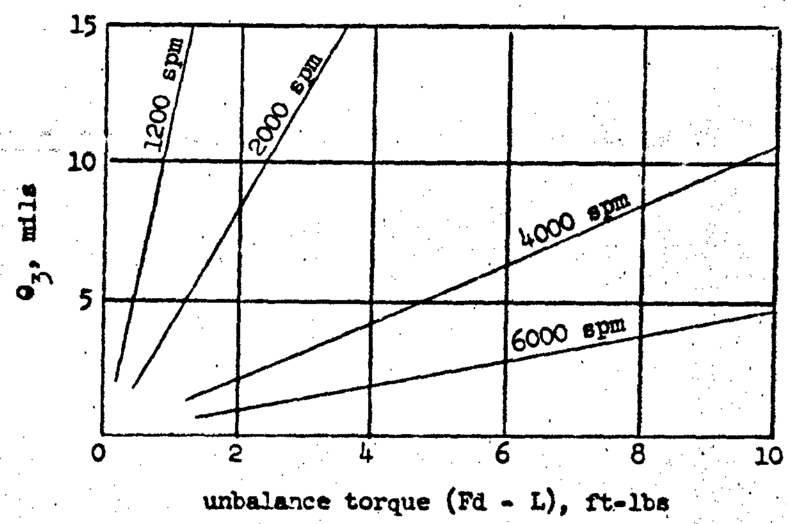
The term (Fd - L) represents a constant unbalance torque acting on the rifle during the burst of three rounds. To show the importance of this torque on Θ_3, the relation is shown below for various rates of fire from a pivoted rifle with the same moment of inertia as the Aircraft Armaments' rifle.



Observe that for small dispersions the desired average unbalance torque must be very small.

It has also been proposed to remove the man from the system because it appears that the man cannot control or adequately keep the rifle on the target. From a theoretical point of view, some mechanical device might be used to provide this decoupling. However, the device must be rather precise and insensitive to the different weights and sizes of different riflemen. In any case, the decoupling must be such that the average torque associated with either inertial, reaction, or friction forces must be less than that shown in the above graph.

These comments do not imply that mechanical devices will not improve the accuracy of the APHHW. It is hoped that the comments will provide better insight of the nature and the magnitude of this particular problem.

(UNCLASSIFIED) RECOMMENDATIONS

In view of the present situation and the stringent limitation on the dispersion (Θ_3) of the APHHW, it is recommended that:

a. Multiple projectiles and multiple-barrel weapons be given consideration.

b. Any mechanical device for improving the accuracy should be evaluated and should show promise before an extensive test program is initiated.

c. Target firings of weapons like the expected APHHW be carried out at much higher rates to check the model over a wider range.

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W. M. Werner
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3. Gay, H. P. Notes on Techniques and Apparatus for Investigating the Effects of Recoil and the Stability of Mounts for Small Arms Weapons. Aberdeen Proving Ground: BRL MR-955, Dec 1955.

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